N x N UNIFORM LOSS ADD/DROP SWITCH

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to optical switches, and particularly to N x N optical switches having add/drop functionality.

2. Technical Background

Large scale optical switch fabrics having path-independent loss-characteristics will be key components in future optical communications systems. Heretofore, there has been some difficulty in fabricating scalable switching components that might be used in such fabrics.

In one approach, an 8 x 8 strictly non-blocking integrated optical matrix switch was fabricated. The switch was implemented using low loss silica on a silicon substrate and achieved a high extinction ratio. The 8 x 8 strictly non-blocking integrated optical matrix switch included 8 rows and 8 columns of switching units. Each column represented a switching stage. Each stage included 8 switching units. Each switching unit included a two Mach-Zehnder Interferometer (MZI) switches operating in tandem using thermooptic switch actuators. The double-MZI switching units are attractive because they achieve high extinction ratios. In fabricating the 8 x 8 matrix switch, eight switching stages are disposed on a silicon substrate having a surface area of about

68mm x 68mm. Subsequently, a 16 x 16 version of the matrix switch was produced. In this approach, sixteen stages were disposed on a silicon substrate having a surface area of 107mm x 100mm.

There are several drawbacks to this approach. First, large scale N x N switch fabrics are needed to meet the demands of present and future high-bandwidth networks. Both designs can only accommodate a small number of components per wafer. For example, only one 8 x 8 switch can be fabricated on a 4" silicon wafer because the total length of the switching units exceeds the diameter of the wafer. Only one 16 x 16 switch can be fabricated on a 6" silicon wafer because the total length of the switching units exceeded the diameter of the wafer. Thus, it may be difficult to produce a large scale N x N switch fabric using this approach. Second, it lacks needed add/drop functionality. Third, it is very difficult to scale these components to produce a larger switch fabric.

Other approaches that have the needed add/drop capability have other drawbacks. The most significant drawback is non-uniform cross-talk characteristics. This occurs when signals exiting the various output and drop ports have different cross-talk levels. These switches are difficult to scale because the non-uniformity of the cross-talk is multiplied and exacerbated at each stage.

What is needed is an optical switch that eliminates the aforementioned disadvantages. A switch is needed that has full add/drop functionality and path-independent loss characteristics. A modular design that allows each switch to be used as a component in a larger switch fabric is also very desirable. This design would also mitigate the effects of first-order cross-talk in a scaled system.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides an N x N modular add/drop switch architecture that addresses the disadvantages presented above. The architecture is based on an N x N switch having full add/drop functionality and path-independent loss characteristics. Thus, the present invention is very flexible, allowing each N x N switch

to be used as a component in a larger switch fabric. The switch design of the present invention also reduces the effects of first-order cross-talk in a scaled system.

One aspect of the present invention is an optical switching system for directing at least one signal between optical fiber networks. The system includes: N-input ports that are adapted to receive the at least one signal from a first optical fiber network; N-output ports, that are adapted to direct the at least one signal out of the switching system and into the first optical fiber network; N-drop ports that are adapted to direct the at least one signal out of the switching system and into a second optical fiber network; and an space division matrix switch coupled to the N-input ports, the N-output ports, and the N-drop ports. The space division matrix switch includes an N x N matrix of interconnected two-stage Mach-Zehnder switching elements, wherein N is an integer. The space division matrix switch is adapted to direct the at least one signal from any one input port of the N-input ports to any one output port of the N output ports, or to direct the at least one signal from any one input port of the N-input ports to a corresponding drop port of the N-drop ports.

In another aspect, the present invention includes a method of switching at least one light signal from a first network to a second network using a space division matrix switch. The space division matrix switch includes: N-first input ports and N-first output ports connected to the first network; at least one second output port corresponding to a predetermined first input port of the N-input ports; and an N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements disposed between the N-first input ports on an input side of the switch, and the N-first output ports and the at least one second output port on an output side of the switch. The space division matrix switch is adapted to route the at least one signal from any of the N-input ports to any of the N output ports. N is an integer. The method includes the steps of adding a drop port connection between a second network input port and the at least one second output port, directing the at least one signal into the predetermined first input port; and actuating the space division matrix switch to select the at least one second output port, wherein the at least one signal is directed into the drop port connection and into the second network.

In another aspect, the present invention includes a method of switching at least one light signal from a second network to a first network using an space division matrix switch. The space division matrix switch includes: N-first input ports and N-first output ports connected to the first network; at least one second input port corresponding to a predetermined first output port; and an N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements disposed between the N-first input ports and the at least one second input port on an input side of the space division matrix switch, and the N-first output ports disposed on an output side of the switch. The space division matrix switch is adapted to route a light signal from any of the N-input ports to any of the N output ports, wherein N is an integer. The method includes the steps of adding an add port connection between a second network output port and the at least one second input port, directing the at least one light signal from the second network output port into the add port connection, and actuating the space division matrix switch to select the at least one second input port, wherein the at least one light signal is directed from the at least one second input port and into the predetermined output port.

In another aspect, the present invention includes a method of fabricating a modular space division matrix switching system, the method including the steps of: providing a plurality of space division matrix switches, each space division matrix switch of the plurality of space division matrix switches including an N x N matrix of interconnected two-stage Mach-Zehnder switching elements, N-input ports, N-add ports, N-output ports, and N-drop ports, wherein N is an integer; and interconnecting the plurality of space division matrix switches by connecting at least one drop port of the N-drop ports of a first space division matrix switch to at least one input port of the N-input ports of a second space division matrix switch.

In another aspect, the present invention includes a method of fabricating a modular space division matrix switching system. The method including the steps of: providing a plurality of space division matrix switches, each space division matrix switch of the plurality of space division matrix switches including an N x N matrix of interconnected two-stage Mach Zehnder switching elements, N-input ports, N-add ports, N-output ports, and N-drop ports, wherein N is an integer; and interconnecting

the plurality of space division matrix switches by connecting at least one add port of the N-add ports of a first space division matrix switch to at least one output port of the N-output ports of a second space division matrix switch.

In another aspect, the present invention includes a method of fabricating a modular switching system having (j x k) space division matrix switches (j, k), wherein j is a row variable and k is a column variable in a matrix space uniquely identifying each space division matrix switch (j, k). Each of the (j x k) space division matrix switches includes an N x N matrix of interconnected Mach-Zehnder switching units. The method including the steps of: connecting the N-output ports of space division matrix switch (j, k) to the N-add ports of space division matrix switch (j+1, k); and connecting the N-drop ports of space division matrix switch (j, k) to the N-input ports of space division matrix switch (j, k+1).

In another aspect, the present invention includes a method of upgrading an optical network having a first switch, the first switch including a first N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements coupled to N-first input ports, N-first output ports, N-unused input ports, and N-unused output ports. The method comprising the steps of: providing at least one second space division matrix switch including a second N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements coupled to N-second input ports and N-second output ports; and coupling at least one of the N-second output ports to at least one of the N-unused inputs to accommodate an add signal, wherein signal traffic is not interrupted during the step of coupling.

In another aspect, the present invention includes an optical device for directing at least one signal. The device including a switch portion having N rows and N columns of interconnected double-Mach-Zehnder thermooptic switching units, wherein N is an integer. The switch portion is adapted to direct the at least one signal from any input port of the switch portion to any output of the switch portion. A signal processing stage is connected to the N^{th} column of the switch portion, the signal processing stage including N-processing units, each processing unit of the N-processing units being connected to a switching unit disposed in the N^{th} column of the switching portion.

Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principles and operation of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic of an optical switch in accordance with a first embodiment of the present invention;

Figure 2 is a detail view of a switching element used in the optical switch shown in Figure 1;

Figure 3 is a schematic of an optical switch component in accordance with a second embodiment of the present invention;

Figure 4 is a detail view of a processing unit shown in Figure 3;

Figure 5 is a schematic of an optical switch component in accordance with a third embodiment of the present invention;

Figure 6 is a schematic of an optical switching system in accordance with a fourth embodiment of the present invention;

Figure 7 is a cabling schematic of the optical switching system depicted in Figure 6; and

Figure 8 is a schematic of a process of upgrading an optical switching system in accordance with a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. An exemplary embodiment of the optical switching system of the present invention is shown in Figure 1, and is designated generally throughout by reference numeral 10.

In accordance with the invention, the present invention for an optical switching system 10 includes an optical switch 20 that has an N x N matrix of interconnected switching elements 22 which are actuated to direct a light signal from any one of input ports 12 to any one of output ports 14. Switch 20 also will direct an input signal from any one of input ports 12 to a corresponding drop port 18. Optical switch 20 is also actuated to direct an add signal from any add port 16 to its corresponding output port 14. Thus, optical switching system 10 provides an N x N uniform loss full add/drop switching architecture based on N x N modular switch 20. Modular switch 20 has full add/drop functionality and path-independent loss characteristics. Optical switching system 10 is also very flexible. It can be used by itself, or as a component in a larger switch fabric. When used in a tiled switch fabric, system 10 exhibits reduced first-order cross-talk characteristics.

As embodied herein, and depicted in Figure 1, a schematic of optical switching system 10 in accordance with a first embodiment of the present invention is disclosed. System 10 includes space division optical switch 20 which is connected to N-input ports 12, N-output ports 14, N-add ports 16, and N-drop ports 18, where N is an integer. In the example shown in Figure 1, N = 8. One of ordinary skill in the art will recognize that N can equal other values such as 16 or 32. Space division optical switch 20 includes N-columns and N-rows of switching elements 22. Each switching element 22 includes a two-stage dilated Mach-Zehnder design which will be discussed more completely below. Switching system 10 also includes a controller that individually actuates each switching element 22 to route a light signal from any input 12 to any

output 14. If the drop functionality of switch 20 is used, the light signal will be directed from an input port 12 to a corresponding drop port 18. Referring to Figure 1, if a signal directed into input port 12 – 4 is to be dropped, the signal will be dropped from drop port 18-4. If the add functionality of the switch is used, a signal directed into switch 20 from add port 16 will be directed into a corresponding output port 16. Thus, a light signal directed into add port 16-6 will be directed out of switch 20 from output port 14-6.

Figures 2A and 2B are detail views of a Mach-Zehnder (MZI) switching element 22 used in a space division optical matrix switch 20 shown in Figure 1. These Figures depict an example of the two-stage dilated architecture that uses two-1 x 2 switches operating in tandem. Switching element 22 includes input MZI 220 and output MZI 224. MZI 220 is actuated by thermooptic actuator 222. MZI 224 is actuated by thermooptic actuator 226. It will be apparent to those of ordinary skill in the pertinent art that modifications and variations can be made to actuators 222 and 226 of the present invention. For example, actuators 222 and 226 may be implemented using piezoelectric or electrooptic actuators. Figure 2A depicts the off-state of actuators 222 and 226. The input coupler of an MZI operates to divide the signal power between the two legs of the MZI. However, the coupler introduces a phase shift between the signals propagating in each arm. The light signals are recombined by the second coupler of the MZI. The light signal is extant in the upper arm by the constructive interference of light, whereas it is destroyed in the lower arm by destructive interference. Thus, the light signal exits the MZI from the upper leg. Theoretically, all of the light signal is present in the upper leg and none is present in the lower leg.

One of ordinary skill in the art will recognize that the space division matrix switch design of the present invention is a path-independent loss device. The addition of add/drop functionality is very important for modular designs and allows the switch to be scaled into larger switch fabrics.

In Figure 2A, element 22 is in the off-state. Light signal L_{s1} is directed into MZI 220 from input lead 230 and is directed directed into output lead 236 by the process

described above. However, a small portion of the light signal L_{s1} leaks into the bottom leg as first-order cross-talk signal δ. The function of output MZI 224 in the off-state is to direct first-order cross-talk signal δ into termination 238. It is noted that a portion of first-order cross-talk signal δ leaks into the bottom leg as second-order cross-talk signal δ^2. Second-order cross-talk signal δ^2 will be propagated through switch 20.

In Figure 2B, actuators 222 and 226 are in the on-state. The lower legs of MZI 220 and MZI 224 are heated and the refractive index of the actuated legs are altered, changing the path length difference between the upper and lower legs of each MZI 220 and 224. Thus, when a light signal is recombined by the second coupler of the MZI, it is destroyed in the upper arm by the destructive interference of light, and present in the lower arm by constructive interference. The light signal exits the MZI from the lower leg. In theory, all of the light signal should be present in the lower leg and none should be present in the upper leg. However, first-order cross-talk signal δ is leaked into the upper arm and directed into output lead 236. When switching element 22 is implemented using two-1 x 2 switches as shown in Figures 2A and 2B, there will be N-first-order cross-talk signals δ. Switch 20 is adapted to direct the N-first-order cross-talk signals δ into their respective output ports 18-1 to 18-N, which are connected to fiber pig-tails for termination purposes. Second-order cross-talk signals δ^2 will be the biggest contributors of cross-talk in output ports 14.

Figure 3 is a schematic of an optical switching system in accordance with a second embodiment of the present invention. System 10 includes optical switch 20 which is connected to N-input ports 12, N-output ports 14, N-add ports 16, and N-drop ports 18, where N is an integer. In the example shown in Figure 1, N = 8. As discussed above, one of ordinary skill in the art will recognize that N can equal other values such as 16 or 32. Optical switch 20 includes N-columns and N-rows of switching elements 22. Each switching element 22 is connected to a controller (not shown). The controller can individually actuate each switching element 22 to route a light signal from any input 12 to any output 14. Switching element 22 is of the type shown in Figures 2A and 2B. If the drop functionality of switch 20 is used, the light signal will be directed from an input port 12 to a corresponding drop port 18. Referring

to Figure 1, if a signal directed into input port 12 – 4 is to be dropped, the signal will be dropped from drop port 18-4. If the add functionality of the switch is used, a signal directed into switch 20 from add port 16 will be directed into a corresponding output port 16. Thus, a light signal directed into add port 16-6 will be directed out of switch 20 from output port 14-6.

In the embodiment depicted in Figure 3, cross-talk termination stage 30 is interposed between the drop port lead of each switching element in the Nth column and its corresponding drop port 18-1 to 18-N. Termination stage 30 consists of N-termination units 32. In the first embodiment, drop ports 18 were used to direct first-order cross-talk signals out of switching system 10. Clearly, it not advantageous to direct first-order cross-talk signals into a second network. Thus, termination stage 30 provides system 10 with the capability of terminating first-order cross-talk signals. Figure 4 is a detail view of a termination unit 32 shown in Figure 3. Termination unit 32 includes Mach-Zehnder 320 and thermooptic actuator 322. When actuator 322 is in the on-state, a drop signal is directed into termination lead 324.

Figure 5 is a schematic of an optical switching system 10 in accordance with a third embodiment of the present invention. This embodiment is nearly identical to the one described above with the exeption that a two stage signal processing unit 32 replaces the single stage unit of Figures 3 and 4. One problem associated with the single MZI termination unit 32 is that it will generate a first order cross-talk signal of its own. The two-stage processing unit will terminate this, as well. The two-stage unit can also be configured as a variable optical attenuator.

Figure 6 is a schematic of modular optical switching system 100 in accordance with a fourth embodiment of the present invention. Modular system 100 is based on switching system 10 described in the first three embodiments discussed above. Switching system 10 is used as a switching component to build a larger jN x kN switch fabric, wherein j, k, and N are integers. Integer j refers to the number of rows in the larger fabric, whereas integer k refers to the number of columns in the larger fabric. For example, modular system 100 can be configured as a 2N x N system, an N x 2N system, a jN x N system, or an N x kN system, as well as a jN x kN modular system. The

modular 4N x 4N system depicted in Figure 7 is merely a representative example. Modular system 100 includes identical switching systems 10, 40, 50, and 60. Add ports 16 of system 10 are connected to output ports 44 of system 40. Drop ports 18 of system 10 are connected to input ports 52 of system 50. In fact, modular system 100 can be characterized as a (j x k) matix space wherein the output ports of optical switch (j, k) are connected to the add ports of optical switch (j+1, k), and the drop ports of optical switch (j,k) are connected to the input ports of optical switch (j, k+1). In this arrangement, the input ports 12 and 42 of the first column are used as system input ports 120. In like manner, first row input ports 46 and 66 become system input ports 160. Nth column drop ports 58 and 68 are utilized as system drop ports 180. Finally, Nth row outputs 14 and 54 are used as system outputs 140.

Figure 7 is a cabling schematic of the modular optical switching system depicted in Figure 6. Figure 7 shows how system 10 can be upgraded after deployment. Using the method described above, multi-fiber cables 70 having array connectors 72 and 74 at either end are used to interconnect systems 10, 40, 50, and 60. As shown, the various ports of systems 10, 40, 50, and 60 are terminated by pigtail arrays 76. Arrays 76 are connected to connectors 72 or 74, as shown.

Figure 8 is a schematic of a process of upgrading an optical switching system in accordance with a fifth embodiment of the present invention. In this instance, system 10 is in service when the process of upgrading commences. For example, add ports 162 and 164 are directing add signals into system 10 from an existing add connection. Similarly, drop ports 182 and 184 are directing network traffic from system 10 into a second network via existing drop connections. Instead of interrupting existing add/drop traffic during the expansion of switch system 10 into modular system 100, the connections are not disturbed until it is convenient. For example, during a regularly scheduled network maintenance period, or during a network reconfiguration when the existing connections are no longer being used.

It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the

modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. An optical switching system for directing at least one signal between optical fiber networks, the system comprising:

N-input ports, each being adapted to receive the at least one signal from a first optical fiber network;

N-output ports, each being adapted to direct the at least one signal out of the switching system and into the first optical fiber network;

N-drop ports, each being adapted to direct the at least one signal out of the switching system and into a second optical fiber network; and

a space division matrix switch coupled to the N-input ports, the N-output ports, and the N-drop ports, the space division matrix switch including an N x N matrix of interconnected two-stage Mach-Zehnder switching elements, wherein N is an integer, and the space division matrix switch is adapted to direct the at least one signal from any one input port of the N-input ports to any one output port of the N output ports, or to direct the at least one signal from any one input port of the N-input ports to a corresponding drop port of the N-drop ports.

2. The system of claim 1, further comprising:

N-add ports coupled to the space division matrix switch, each one of the N-add ports being adapted to receive at least one add signal from either the first network, the second network, or a third optical fiber network wherein the add signal received from an add port is routed to a corresponding output port of the N-output ports.

3. The system of claim 2, wherein the space division matrix switch includes N rows and N columns of switching elements, each switching element in the first column of the N columns has a first input connected to an input port of the N-input ports, and a second input connected to an add port of the N-add ports.

4. The system of claim 3, wherein each switching element in the N^{th} column has a first output lead connected to an output port of the N-output ports, and a second output connected to a drop port of the N-drop ports.

5. The system of claim 1, wherein the switching elements are 2 x 2 space division matrix switches.

6. The system of claim 1, wherein the switching elements are comprised of two interconnected 1 x 2 space division matrix switches.

7. The system of claim 6, wherein the Mach-Zehnder interferometer switches include thermooptic actuators.

8. The system of claim 6, wherein the Mach-Zehnder interferometer switches include piezoelectric actuators.

9. The system of claim 6, wherein the Mach-Zehnder interferometer switches include electrooptic actuators.

10. A method of switching at least one light signal from a first network to a second network using an space division matrix switch, the space division matrix switch including N-first input ports and N-first output ports connected to the first network, at

least one second output port corresponding to a predetermined first input port of the N-input ports, and an N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements disposed between the N-first input ports on an input side, and the N-first output ports and the at least one second output port on an output side, the space division matrix switch being adapted to route the at least one signal from any of the N-input ports to any of the N output ports, wherein N is an integer, the method comprising the steps of:

adding a drop port connection between a second network input port and the at least one second output port;

directing the at least one signal into the predetermined first input port; and

actuating the space division matrix switch to select the at least one second output port, wherein the at least one signal is directed into the drop port connection and into the second network.

11. The method of claim 10, wherein the at least one second output port includes N-second output ports, and the step of adding includes adding N-drop port connections between the N-second output ports and the second network.

12. A method of switching at least one light signal from a second network to a first network using an space division matrix switch, the space division matrix switch including N-first input ports and N-first output ports connected to the first network, at least one second input port corresponding to a predetermined first output port, and an N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements disposed between the N-first input ports and the at least one second input port on an input side of the space division matrix switch, and the N-first output ports disposed on an output side of the switch, the space division matrix switch being adapted to route a

light signal from any of the N-input ports to any of the N output ports, wherein N is an integer, the method comprising the steps of:

adding an add port connection between a second network output port and the at least one second input port;

directing the at least one light signal from the second network output port into the add port connection; and

actuating the space division matrix switch to select the at least one second input port, wherein the at least one light signal is directed from the at least one second input port and into the predetermined output port.

13. The method of claim 12, wherein the at least one second input port includes N-second input ports, and the step of adding includes adding N-add port connections between the N-second input ports and the second network.

14. A method of fabricating a modular space division matrix switching system, the method comprising the steps of:

providing a plurality of space division matrix switches, each space division matrix switch of the plurality of space division matrix switches including an N x N matrix of interconnected Mach-Zehnder switching elements, N-input ports, N-add ports, N-output ports, and N-drop ports, wherein N is an integer; and

interconnecting the plurality of space division matrix switches by connecting at least one drop port of the N-drop ports of a first space division matrix switch to at least one input port of the N-input ports of a second space division matrix switch.

15. A method of fabricating a modular space division matrix switching system, the method comprising the steps of:

providing a plurality of space division matrix switches, each space division matrix switch of the plurality of space division matrix switches including an N x N matrix of interconnected two-stage Mach-Zehnder switching elements, N-input ports, N-add ports, N-output ports, and N-drop ports, wherein N is an integer; and

interconnecting the plurality of space division matrix switches by connecting at least one add port of the N-add ports of a first space division matrix switch to at least one output port of the N-output ports of a second space division matrix switch.

16. A method of fabricating a modular switching system having (j x k) space division matrix switches (j, k), wherein j is a row variable and k is a column variable in a matrix space uniquely identifying each space division matrix switch (j, k), each of (j x k) space division matrix switches including an N x N matrix of interconnected Mach-Zehnder switching units, the method comprising the steps of:

connecting the N-output ports of space division matrix switch (j, k) to the N-add ports of space division matrix switch (j+1, k); and

connecting the N-drop ports of space division matrix switch (j, k) to the N-input ports of space division matrix switch (j, k+1).

17. The method of claim 16, wherein the add ports of space division matrix switches (1, k) are coupled to the add ports of the modular switching system.

18. The method of claim 16, wherein the input ports of space division matrix switches (j, 1) are coupled to the input ports of the modular switching system.

19. The method of claim 16, wherein the output ports of space division matrix switches (N, k) are coupled to the output ports of the modular switching system.

20. The method of claim 16, wherein the drop ports of space division matrix switches (j, N) are coupled to the drop ports of the modular switching system.

21. A method of upgrading an optical network having a first switch, the first switch including a first N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements coupled to N-first input ports, N-first output ports, N-unused input ports, and N-unused output ports, the method comprising the steps of:

providing at least one second space division matrix switch including a second N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements coupled to N-second input ports and N-second output ports; and

coupling at least one of the N-second output ports to at least one of the N-unused inputs to accommodate an add signal, wherein signal traffic is not interrupted during the step of coupling.

22. The method of claim 21, wherein the optical network and the first space division matrix switch are in-service during the step of coupling.

23. The method of claim 21, wherein the N-unused inputs are configured to include an inactive first add port, and an active first add port coupled to existing add connection not connected to a second output port, and the step of coupling only includes coupling the inactive first add port to a corresponding one of the N-second output ports while leaving the existing add connection intact.

24. The method of claim 23, further comprising the steps of:

de-coupling the active first add port from the existing add connection to form a deactivated first add port, wherein the step of de-coupling occurs during a network maintenance period; and

re-coupling the deactivated first add port to a corresponding one of the N-second output ports.

25. The method of claim 21, wherein the at least one second space division matrix switch includes a third space division matrix switch including a third N x N matrix of interconnected two-stage thermooptic Mach-Zehnder switching elements coupled to N-third input ports and N-third output ports.

26. The method of claim 25, further comprising the step of coupling at least one of the N-third input ports to at least one of the N-unused first outputs to accommodate a drop signal without interrupting signal traffic.

27. The method of claim 26, wherein the optical network and the first space division matrix switch are in service.

28. The method of claim 25, wherein the N-unused first outputs are configured to include an inactive first drop port and an active first drop port coupled to existing drop connection, and the step of coupling includes coupling the inactive first drop port to a corresponding one of the N-third input ports to form an active first drop port.

29. The method of claim 28, further comprising the steps of:

de-coupling the active first drop port from the existing drop connection to form a deactivated first drop port, wherein the de-coupling occurs during a network maintenance period; and

re-coupling the deactivated first drop port to a corresponding one of the N-third input ports.

29. An optical device for directing at least one signal, the device comprising:

a switch portion including N rows and N columns of interconnected double-Mach-Zehnder thermooptic switching units, wherein N is an integer, and the switch portion is adapted to direct the at least one signal from any input port of the switch portion to any output of the switch portion; and

a signal processing stage connected to the N^{th} column of the switch portion, the signal processing stage including N-processing units, each processing unit of the N-processing units being connected to a switching unit disposed in the N^{th} column of the switching portion.

30. The optical device of claim 29, wherein the processing unit is comprised of two interconnected 1 x 2 thermooptic Mach-Zehnder interferometers.

31. The optical device of claim 29, wherein the processing unit is a signal attenuation unit.

32. The optical device of claim 29, wherein the processing unit is a signal termination unit adapted to direct a first order cross-talk signal into a drop port.

N x N UNIFORM LOSS ADD/DROP SWITCH

ABSTRACT OF THE INVENTION

The present invention provides an N x N uniform loss full add/drop switching system architecture. The architecture is based on an N x N space division matrix switch having full add/drop functionality and path-independent loss characteristics. The present invention is very flexible, allowing each switch to be used as a component in a tiled larger switch fabric. The switch design of the present invention also reduces the effects of first-order cross-talk in a tiled system.

The N x N space division matrix switch has an N x N matrix of interconnected two-stage Mach-Zehnder thermooptic switching elements. The switching elements can be actuated to direct a light signal from any one of input ports to any one of output ports. The switch can also direct an input signal from any one of input ports to its corresponding drop port. The optical switch can also be actuated to direct an add signal from any add port to its corresponding output port. Thus, the optical switching system provides an N x N uniform loss full add/drop switching architecture based on the N x N modular switch. The modular switch has full add/drop functionality and path-independent loss characteristics. The optical switching system is also very flexible in that it can be used by itself, or as a component in a larger switch fabric. When used in a tiled switch fabric, the optical switching system exhibits reduced first-order cross-talk characteristics.